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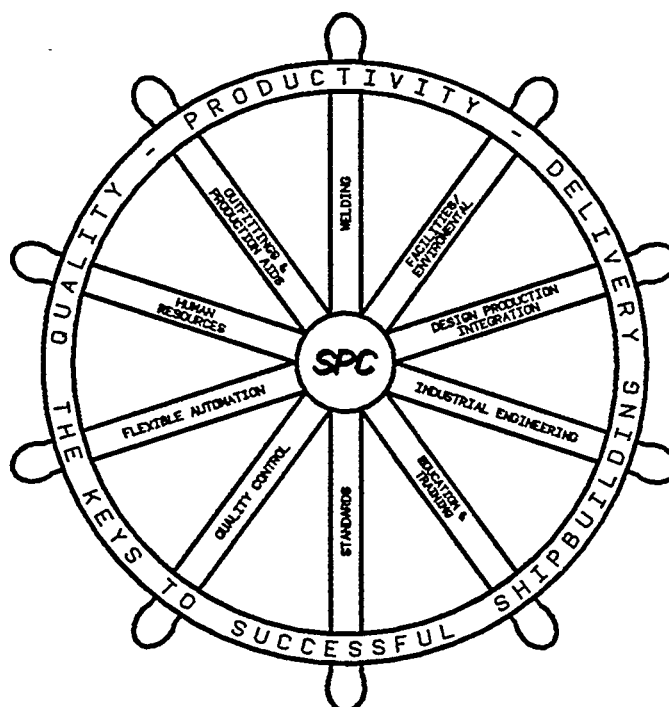
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The Lay-Up and Reactivation of LNG Tankers: Lessons Learned

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The Liquid Natural Gas (LNG) Industry went from a projected boom in the 1970's to a contracted industry in the 1980's, when many ships were either permanently or temporarily laid up. In the 1990's, many laid up LNG carriers are being reactivated after as many as 12 years in lay-up. While the capital cost of an LNG carrier should dictate maximum preservation of the asset, the LNG industry is not immune to having to make hard economic decisions during slack times. In this paper, the authors present specific alternate lay-up procedures, together with the relative costs of these alternatives.

LNG carriers are steam vessels, as are many of the vessels in the Ready Reserve Fleet (RRF). However, many of the conclusions reached can also be applied to motor vessels, and as such could be of interest to operators and shipyards in all phases of the RRF program.

The subjects of dehumidification, inert gas plants, ballast tank coatings and drydocking, among others, will be discussed.

THE LAY-UP OF VESSELS - INTRODUCTION

Many students, who cannot bear to part with their restored auto when they go to college, but who also know it won't be able to travel that far, put the car up on blocks so that it may be brought back to life again the following summer. As some may remember, the time required to restore the car to operation that following summer depended entirely on the care taken in laying up the car.

While no shipowner wants to think about lay-up, as it is not a particularly profitable mode of operation, the fact remains that for all trades and ship types, temporary, short term, or even long term lay-up is a possibility. As an example

of ships that routinely lay up, the U.S. Great Lakes Fleet lays up each winter due to severe firming of lake water. The ships in this Fleet, however, are some of the best maintained in the world, because this annual lay-up period is used to advantage. Because of the lay-up procedures employed and the maintenance work carried out during the lay-up period, these ships re-enter service in the spring with few problems.

Although lay-up means that there is no trade for a vessel and, therefore, revenue has stopped, there are maintenance areas where costs should not be cut, as asset depreciation will offset any potential, short-term savings.

As an example of the merits of proper lay-up, the following account is relevant. A few years ago a container ship operator laid up two identical steam vessels. Identical De-Humidifying (D-H) equipment was installed on each vessel, and the same deactivation procedures were followed.

Ship A was laid up in Yokohama, Japan, and due to local law, the Master and Chief Engineer were kept onboard to tend the vessel. Ship B was laid up in Alameda, California, and, as a cost-cutting measure, no on-board personnel were retained. Instead, the vessel management staff and port engineering staff from the owner's California office visited the vessel on a regular basis, usually once per week.

Six months later both ships were reactivated. Ship A was reactivated on time and on budget, without any deactivation-related equipment or motor loss.

Ship B, on the other hand, suffered damage to both main circulating pump motors, both main condensate pump motors, both forced draft fan motors, and both fuel oil service pump motors. As a result, the ship was delayed going into

service. The short term savings gained during the lay-up period of Ship B were eclipsed by the resulting increased reactivation costs and loss of revenue due to the delay in returning to service.

The U.S. Ready Reserve Fleet (RRF) ships are specifically intended, but not designed, to spend the majority of their time in a lay-up condition. The vessels are laid up in a manner intended to, hopefully, minimize reactivation costs and time. The reactivation of these ships has not, as demonstrated by the Desert Shield/Desert Storm mobilization, been as efficient and reliable as planned. One reason for higher than anticipated costs is the simultaneous reactivation of a large number of vessels into a diminishing number of shipyards available for ship repair and/or reactivation in the U.S. The limited amount of available reactivation shipyard resources produces a work overload, requiring significant overtime hours, and substantially increasing reactivation cost. The lay-up/reactivation program could be configured to even out the peaks and valleys and, thereby, balance lay-up and reactivation costs and improve ship availability. The purpose of this paper is to present ways in which to balance lay-up and reactivation costs.

In the Liquid Natural Gas (LNG) trade, the authors have gained considerable experience in laying up and breaking out steam powered LNG vessels. This experience has been gained over the last 20 years starting with the delivery, lay-up and breakout of the LNG carriers for the Algeria I LNG project in the early seventies. The Algeria I project was subsequently shut down and the tankers laid up in 1981. Finally, the restart of the Algeria to Cove Point, Maryland. LNG trade requires the reactivation of two of the ships laid up in 1981; this work is currently in progress. The experience gained, and the lessons learned, form the basis for this paper.

ATMOSPHERIC MAINTENANCE DURING LAY-UP

The desired end result of lay-up should be to hold the condition of steel, machinery and systems in a near-operating condition, and make allowances for environmental degradation. To carry out this aim, the principle method of preserving internal spaces is dehumidification.

Dehumidification Equipment.

Traditional Dehumidification Equipment (D-H) units remove moisture from the air by

either heating the air and then moving it through desiccant towers, or by moving the air past refrigerant coils. The D-H units are temporary units which have to be mounted in either environmental structures or, if there is sufficient room, inside the house structure of the ship in order to provide protection from the elements. In marine, corrosive salt atmospheres, the life of desiccant type D-H units can be as short as one year. Similarly, non-marine refrigeration type D-H units are prone to corroding beyond repair in similar time periods.

Further, renting, moving and shipping D-H units for lay-up is expensive. For long term lay-up, D-H units run about \$100 per day. For short term lay-up, \$250 per day plus installation can be expected. Installation costs of either desiccant or refrigeration type D-H are similar, and are on the order of \$10,000 to \$30,000. The installation of temporary ducting, wiring, etc. increases the cost further. This ducting can also hamper repair work and general access to spaces. The cost of D-H equipment continues with the removal of this temporary equipment. Total temporary D-H costs, of either desiccant type or refrigerant type, are high enough to cause most owners to forego their use for a short term lay-up. However, short term lay-up often turns out to be longer than expected, and the ship suffers from lack of D-H during this period. The deteriorating effects of corrosion on the ship and equipment begin as soon as equipment is secured. Failure to dehumidify machinery spaces during even short term lay-up can result in the need for expensive repairs at reactivation time.

In place of temporary D-H units, which must be installed whenever the ship is laid up and subsequently removed upon reactivation, refrigeration units intended for 40-foot containers can be permanently mounted in frames on the side of the engine room casing in a protected area. These units can be configured to run on electricity, diesel oil or Liquid Petroleum Gas (LPG), and can maintain D-H by means of refrigeration or heating. For short term lay-ups when the machinery plant is to be idled, the units need only to be activated. Machinery plant D-H is then immediately available, significantly improving the protection of the asset. The units cost approximately \$11,000 each and can be installed by the crew. Shipyard installation adds an additional \$10,000. Even without auxiliary ducting, the units will maintain an engine room at low humidity for short periods. However, for long lay-up

ate	T°F /H% Ambient	T°F /H% Lower Level	T°F /H% 54' Level	Comments
May '91	92°/78.8%	80°/ 54.4%	80°/44.5%	
July/August '91	85°/82%	86°/85%	88"/83%	1.
September '91	85°/75%	78°/33.4	80°/32.7%	

TABLE I
Temperature & Humidity Readings with
Traditional Desiccant Dehumidifiers

T = Temperature in degrees Fahrenheit
H = Relative Humidity in percent

1. The dehumidification equipment was secured during this period to allow for access to the engine room for maintenance, repair and reactivation work.

Date	T °F / H% Ambient	T °F / H% Lower Level	T °F / H% 54' Level	Comments
March '92	53°/65%	56°/29.1%	58°/26.7%	
May '92	65°/100%	69°/52%	69°/50.8%	
July/August '92	90°/85%	78°/62%	80°/60%	outside doors open & unit running
September '92	75°/80%	65°/60.6%	68°/59.8%	outside vents open
January '93	42°/75%	54°/40.5%	56°/41.8%	vents closed & outside doors cracked

TABLE II
Temperature & Humidity Readings with Permanent
Container Type Refrigerant Dehumidifier

periods, it is helpful to run light, flexible temporary ducting to the engine room supply blower(s) ducting, and thereby utilize the vessel's own ventilation system(s) to distribute the dry air. The addition of temporary ducting increases the cost of D-H. The amount of temporary ducting is significantly reduced over the use of totally temporary D-H systems, however.

Table I illustrates the maintenance of a dehumidified atmosphere with traditional D-H units. Table I can be compared to Table II which illustrates the maintenance of a dehumidified

atmosphere with a permanently fitted container type refrigeration unit. In summer months, the permanent unit maintains the lower engine room at 12°F below ambient temperature during lay-up with considerable work taking place in the engine room. This data has been taken as a regular part of lay-up inspections aboard the LNG Carriers *ARZEW* and *SOUTHERN*.

Design Considerations of D-H Equipment.

D-H equipment is limited as to the volume

Features	Typical Temporary Desiccant Type Dehumidifiers	Typical Permanent Container Type Refrigeration Dehumidifier
Weatherproof	No	Yes
Heat & Cool	No	Yes
Maintenance Cost 1st Year	\$1,700.00	\$0.00
E.R. Access w/unit in place	No	Yes
Storage on Board	No	Yes
ABS & Lloyd's Compliant	No	Yes
Dimensions	9' X 4'-8" X 5'-8"	7'-4" X 6'-8" X 16"
Weight	2100 lbs	1100 lbs.
Price Less Installation	\$15,130.00	\$10,865.00

TABLE III
Comparison of Temporary D-H Units to
Permanent Container Refrigeration Units

of air that can be treated per unit time. Usually D-H systems are sized and designed to maintain a dry atmosphere once a space has been dehumidified, taking into account ambient air conditions and air infiltration. The time taken to reach acceptable D-H levels can be significant and is chiefly effected by the capacity of the D-H units, arrangement of ducting, and air infiltration. Consequently, dehumidified spaces must be sealed for best results, since frequent access to the space degrades the dehumidified condition of the atmosphere in the space. If a space must be frequently accessible, dehumidifying the adjacent passageway or providing an airlock (two separated doors) at the entry, may be required. As an example, the 600,000 cubic foot engine room of an LNG carrier using the permanent container refrigeration unit (with distributed ducting) at a rated air flow throughput capacity of 150 cubic feet per minute takes about one week to achieve satisfactory humidity levels throughout the engine room. With distributed ducting, therefore, approximately 2.5 engine room air changes are required to reach acceptable humidity levels.

By comparing Tables I and II it can be seen that the permanent D-H equipment installation was able to maintain comparable D-H levels to the temporary installation. Even during peri-

ods with high ambient humidity, July/August '92, and with the spaces open, the permanent D-H installation was able to hold the engine room humidity at an acceptable level. It was not possible to accomplish the same level of protection with the temporary installation. Table III compares features and particulars of typical temporary D-H units to a typical container refrigeration unit for use as a permanently installed engine room D-H unit.

Dehumidified air is the only method of atmospheric corrosion control acceptable for spaces accessible by humans. However, for spaces that are not accessible for personnel access, other alternatives exist. Specifically, corrosion can be controlled by reducing oxygen content in the atmosphere to the point that oxidation, or corrosion, is inhibited. There are two methods by which this may accomplished. The first is the reduction of the oxygen content by the combustion of hydrocarbon fuel in a stoichiometric combustion. These units are generally referred to as Inert Gas (I. G.) plants. The second method is by the use of industrial purity nitrogen. The method of oxygen control is by displacing the oxygen rich atmosphere with an oxygen depleted atmosphere.

Inert Gas Plants.

Tankers, LPG and LNG carriers are fitted with primary inert gas plants which put out a product gas principally composed of carbon dioxide and nitrogen; oxygen levels are less than 2% by volume. Cargo tanks which are piped to these systems can be inerted with this gas by displacing the atmosphere in the tanks with the oxygen depleted product gas, so that oxidation (corrosion) is halted through the lack of oxygen. When used in conventional tankers, however, this process does not guarantee that the cargo tank will be dry. Residual cargo or condensation can remain in the tank. This moisture can cause problems. For instance, conventional tankers generally use stack gas from the main engine as the feed gas to the I.G. plant, which cleans the gas by scrubbing before directing the gas to the cargo tanks. The gas produced in this manner may still contain sulfur and other stack by-products, that, when combined with moisture in the cargo tanks, will produce acids which can attack the tanks even though oxidation is reduced due to the lack of oxygen. The components of the product gas of any inert gas source must be verified, and the tanks thoroughly dried before laying up the tank in an inert atmosphere.

LPG and LNG carriers, on the other hand, are fitted with independently fired I.G. plants that use diesel oil as fuel and produce a much cleaner and dryer product gas: dew points are generally in the -60 degree F range. In as much as the cargo is very clean, with no residue left after discharge and warm-up, the use of the I.G. plant product gas for providing an inert, anti-corrosion atmosphere in the cargo tanks, is the standard method of preservation of the tanks.

While it may be tempting to inert ballast tanks or the ullage space over ballast water in ballast tanks, this should only be carried out under strict procedures where ballast tanks are sealed and proven tight, warning signs are placed on all access plates and surrounding enclosed areas are carefully monitored. Tank vents must be sealed to prevent routine breathing, but still provide over and under pressure protection. The composition of the product gas of the I.G. plant should be checked to ensure that acids will not be formed when in contact with the sea water and moisture in the ballast tanks.

It should be pointed out that both types of I.G. plants can produce dangerous levels of carbon monoxide. Prior to allowing manned entry

into the space, the atmosphere should be checked not only for sufficient oxygen, but also for acceptable levels of carbon monoxide. Gas detection meters that read both oxygen and carbon monoxide concentrations must be utilized prior to allowing personnel to enter the space. In addition the personnel entering the space should carry the meters with them to continuously monitor the oxygen and carbon monoxide levels of the space.

Nitrogen.

As most LNG carriers use industrial grade nitrogen for inerting cargo tank barrier spaces, liquid nitrogen dewars and vaporization equipment are already in place. Dry nitrogen from the gas burning purge system can be circulated through boiler tubes, steam piping, turbines and gear cases. This will remove residual moisture from these systems, while providing an inert, dry, noncorrosive atmosphere for lay-up.

Using Liquid Nitrogen from the cargo system dewars during lay-up to dry out and/or maintain an inert atmosphere in the cargo tanks, piping, boilers, etc. is an excellent technique. There are drawbacks, however. While replenishment of liquid nitrogen at a lay-up pier is not a problem, replenishment at an anchorage would be very costly. In addition, liquid nitrogen at -320°F will crack service craft deck plates or ship steel if it is spilled in transit or during liquid transfer operations. Consequently, lay-up personnel must be trained in the safe handling of this cryogenic liquid. An alternative supply of industrial grade gaseous nitrogen has recently become economically available. Air separation plants provide ambient temperature nitrogen by membrane separation of air or by pressure swing absorption techniques.

Air separation plants not only eliminate recurring liquid nitrogen purchase costs, but also provide an unlimited nitrogen supply regardless of ship location in lay-up, as they require only electric power to operate. This same unlimited supply of nitrogen also permits control air systems, etc. to be purged with nitrogen, thereby improving system longevity. Power consumption is comparable to that required for an air compressor to supply the desired delivery pressure and flow rate. The plants generally pay for themselves in less than a year depending upon total nitrogen consumption.

Remotely Located Spaces.

It is difficult and probably not cost-effective to totally dehumidify spaces such as the bow thruster rooms and steering gear rooms using the previously described methods. In these remote spaces, heating strips, small portable desiccant type D-H units and, sometimes, refrigerant type D-H units can be employed, either by themselves or in combination in a localized fashion to protect specific equipment. Preservative coatings can also be applied to further inhibit corrosion. Care must be taken to use a coating that is easy to remove or does not require removal prior to reactivating the equipment.

ALTERNATIVE PRESERVATION TECHNIQUES

While atmospheric control by dehumidification is the generally preferred method of preserving equipment during lay-up, rotating and operating equipment and other preventive maintenance techniques will also provide good results. The principle drawback to employing this technique is that it requires a larger, permanent, skilled staff to perform the extensive maintenance routines required.

This technique was employed on the LNGC *HOWARD BOYD* in March of 1980. The ship delivered a cargo to Cove Point, Maryland and was taken out of service for what was expected to be a short term lay-up, approximately 30 to 60 days. The ship was sent to sea to gas free and inert its tanks. Upon gas freeing, the vessel was laid up at Norshipco, and then, subsequently, transferred to the coal terminal in lower Newport News, Virginia after the short term lay up developed into long term. The top five officers were retained on board the vessel. All other officers and unlicensed crew were discharged. The officers retained on board undertook an extensive lay-up routine and comprehensive preventive maintenance program on the vessel.

All systems were blown down first with air and then with dry nitrogen from the ship's liquid nitrogen dewars. In lieu of dehumidifying machinery spaces, etc., equipment was rotated and operated on a regular basis, and the required preventive maintenance was undertaken. Due to these efforts, in August of that year, the vessel was reactivated in less than forty (40) hours with no failures, and subsequently sailed to the Mediterranean.

Had the lay-up been extended much longer, however, the cost of maintaining the ship in this fashion would have escalated to the point that long term lay-up techniques would have had to have been initiated. It is difficult to predict precisely how long a ship may be required to remain in lay-up. It is, therefore, equally difficult to make economic assessments of the most cost effective lay-up techniques. Had the LNGC *HOWARD BOYD* been fitted with a permanent D-H system, long term techniques could have been initiated immediately, which would have ultimately reduced the lay-up costs.

CONSTRUCTION DETAILS THAT IMPROVE LAY-UP

There are a variety of details and equipment that can be added during construction that will reduce cost the of lay up. Many of these details will also reduce ship maintenance costs.

Towing Fittings.

Towing fittings consisting of deck-mounted towing pads and specially radiused chocks will soon be required to be fitted to tankers as a salvage feature. For any ship in lay-up, towing fittings with pendants to the water give an added measure of safety should the ship be blown off a dock, or somehow lose its anchor gear while at anchor. Towing fittings also allow the ship to be readily and easily towed from lay-up as an alternative to crewing the ship and transiting under its own power. It is often necessary to change lay-up berths. Towing the ship eliminates the expense of reactivating the machinery plant and subsequently reinstating the lay up.

The authors recommend installing these fittings at each end of the ship. The construction and mounting of these fittings as a refit on the bow only, with the ship alongside a pier with crane service available, will cost about \$20,000. If the towing fitting is installed while at an anchorage, the cost can be expected to be in excess of \$50,000. The cost of installing towing fittings during construction should be significantly less than the retrofit cost.

Stainless Steel Kickpipes.

In 10 years of lay-up, the subject LNG Carriers, which have flat decks, pocketed rain water even though they had stern trim. Deposited salts from

operation, together with this wet condition, corroded approximately 60 kickpipes per ship. Even kickpipes that appeared to be sound were found to have pin holes when the decks were recently sandblasted. Water seeped into voids, cofferdams and other spaces through these kickpipes, causing undetected corrosion and coating breakdown. Although the extent of interior corrosion does not, at this time, warrant plate renewal, it is still necessary to remove the corrosion and repair the coating(s); this will be more expensive than it would have been to install stainless steel kickpipes in the first place. Additionally, the cost of renewal of the deteriorated kickpipes will be quite expensive, in excess of \$50,000 per ship. The high cost of renewal is due to the necessity of disconnecting the electrical connections, removing the cables from the kickpipes and then reinstalling and reconnecting the cable after the kickpipe has been renewed. As a further complication and expense, many of the cables terminate at explosion proof hardware which has to be destroyed in order to remove the cable. A significant maintenance problem could have been avoided for a very modest cost during the construction of the ships.

Inset Side Mooring Fittings.

The height of LNG carriers makes them unsuitable for most lay-up piers with respect to the lead of mooring lines. A similar problem exists with car carriers, some Roll-On/Roll-Off Ships (RO/RO) and container ships. For breast lines, in particular, unless there is sufficient land between the ship and the shore, bollard leads will be nearly vertical. In extreme conditions, LNG carriers have pulled shore fittings out of the ground. The release of just one shore fitting, combined with the huge sail area of an LNG carrier, has been sufficient to cause the parting of remaining mooring lines and the unscheduled departure of an LNG Carrier in lay-up.

Inset chocks should have a horizontal pull capacity of at least 100 tons and should be mounted about two to three meters above the deep load line. The bar-type fitting allows multiple cable passes for lay-up, while the horn type may be easier to use for tug assistance, when docking.

Stern Anchor.

Fitting a single wildcat, aft windlass and

centerline hawsepipe with chain and anchor provides greater flexibility with regard to lay-up berthing arrangements. For fiord type lay-ups where the stern can be brought close to shore, the stern anchor can be slipped and the stern chain taken ashore. The stern chain can be tensioned at any time allowing adjustment to shore power lines and piping/hose runs. Temporary anchorages for lay-up are also possible in restricted waterways by utilizing the stern anchor to reduce ship swinging and surging. Even at pier side lay-up berths the stern anchor provides added security to the ship's mooring arrangement when severe weather conditions exist.

The installation of a stern anchoring system is an expensive new construction option. Costs can be expected to be approximately \$750,000.

House Deck Drains.

The house deck drains on the subject LNG Carriers are typically 38mm to 75mm in diameter, and are continually being plugged by falling paint, debris or dirt. The effort to clear the drain strainers and the pipes themselves takes up a considerable amount of a lay-up crew's time (approximately 640 manhours per year) and, presumably, operating crew time when the ships are in service. Larger drains with easily removable inlet screens and without horizontal runs, including sloped horizontal runs, would minimize the problem. Many of these drains run internally to the house, which further complicates maintenance and ultimate replacement. Although internal drains may look nice, they are usually more expensive to install during construction, in addition to being more expensive to maintain. External drains of Glass Reinforced Plastic (GRP) or similar non-corrosive material, where practicable, with a sufficient number of cleanouts to allow direct access to all straight piping runs, would be beneficial to long-term maintenance both in service and in lay-up.

Stack Cover and Access to the top of the Stack.

As all current LNG carriers are steamships, they have boilers which, in lay-up, may or may not be cleaned depending upon time in service since last cleaning, and expected length of lay-up. Regardless of the degree of cleaning, rain water entering the boilers through the stack can soak the floor as well as mix with the residues from burning residual fuel oil, causing corrosion

and totally destroying floor tubes in a short period of time. Tarpaulins over the stack frequently fail in rainstorms, thus a more permanent stack cover is recommended. Access to the top of the stack for installing such a permanent cover without the use of crane or other shoreside services is also recommended.

BALLAST TANK COATINGS

The ballast tanks on the LNGC'S *ARZEW* and *SOUTHERN* were coated with an epoxy based coating system, which has held up extremely well in both dry and wet tanks. Some of the ballast tanks have been filled for over 10 years with no breakdown or blistering of the coating. Humidity control during coating and quality control of the original coating application are credited as the main reason for this outstanding performance. The coating itself has low water permeability, and was applied in excess of 8 mils (D17). Careful attention to the surface preparation and coating of flanges, relief holes and brackets is also evident. The small areas of coating breakdown that have been found will be fitted with anodes during reactivation; no recoating, therefore, is planned. Ballast tank coating is the single most important factor to double hull LNG tanker longevity. Saving construction costs in this area is false economy.

PRE-REACTIVATION WORK

The subject group of LNG carriers were laid up in 1981 and stayed in continuous lay-up until their purchase in late 1990. Upon transferring title to the ships, they were moved, by towing, to a new lay-up berth. Once lay-up procedures were reinstated after the tow, critical sections of the ships and equipment were opened up for inspection in preparation to preparing a reactivation work specification. The water side of the boilers, the cargo and ballast tanks and the internal spaces of the ships were all found to be in excellent condition. In addition to the lay-up procedures previously discussed, the vessels were, and continue to be, manned continuously during the lay-up periods. A lay-up routine consisting of rotating machinery, preventive maintenance, and checking electrical equipment was, and continues to be, followed. Since bringing the ships out of deep lay-up and beginning the reactivation process, all electric motors, switchboards, control consoles and electronic

systems have been powered up with little deterioration noted. The decisions to replace and/or upgrade equipment will, therefore, be based on current and future supportability rather than on equipment deterioration.

The charterer of the ships desires a relatively quick (90-day) reactivation period. In preparing and planning for reactivation, personal computer based project planning and management software was utilized to develop an overall Program Evaluation Review Technique (PERT) chart for pre-activation work, long lead equipment ordering requirements, yard reactivation, gas and sea trials, positioning voyages, etc. A portion of this chart is shown in Figure 1. This section shows the detail of planning for long lead equipment purchases. The first charts produced were astounding, indicating that years would be involved in the reactivation process, far from the ninety days desired by the charterer. Estimates were refined and reactivation specifications were prepared which were bid to a number of U.S. shipyards. In submitting their bids, the shipyards estimated the reactivation shipyard period to be between 8-1/2 and 9 months. Subsequent meetings with the shipyards and review of scheduling revealed that out of over 400 reactivation tasks, approximately 14 tasks took the reactivation period beyond 4 months time. Those 14 tasks have been the subject of close examination, in order to bring the reactivation period closer to the ninety days desired by the charterer. The following work was undertaken as a result of reactivation PERT chart evaluation.

Turbines.

Lead times for replacement parts for the main and generator turbines were found to be up to one year. Consequently the turbines were opened up for inspection so that any parts that may have been required could be ordered in sufficient time. Upon inspection some very long lead parts were found necessary. The turbines were left opened up and D-H reinstated by installing temporary plastic enclosures over the casings. The parts were ordered and when received, many months later, the turbines were reassembled. This removed a long lead item from the original schedule that in fact had not had sufficient time scheduled in the reactivation plan due to the unknown need for long lead replacement parts. Since the work is now completed, it has been deleted from the

Typical PERT Chart Detail

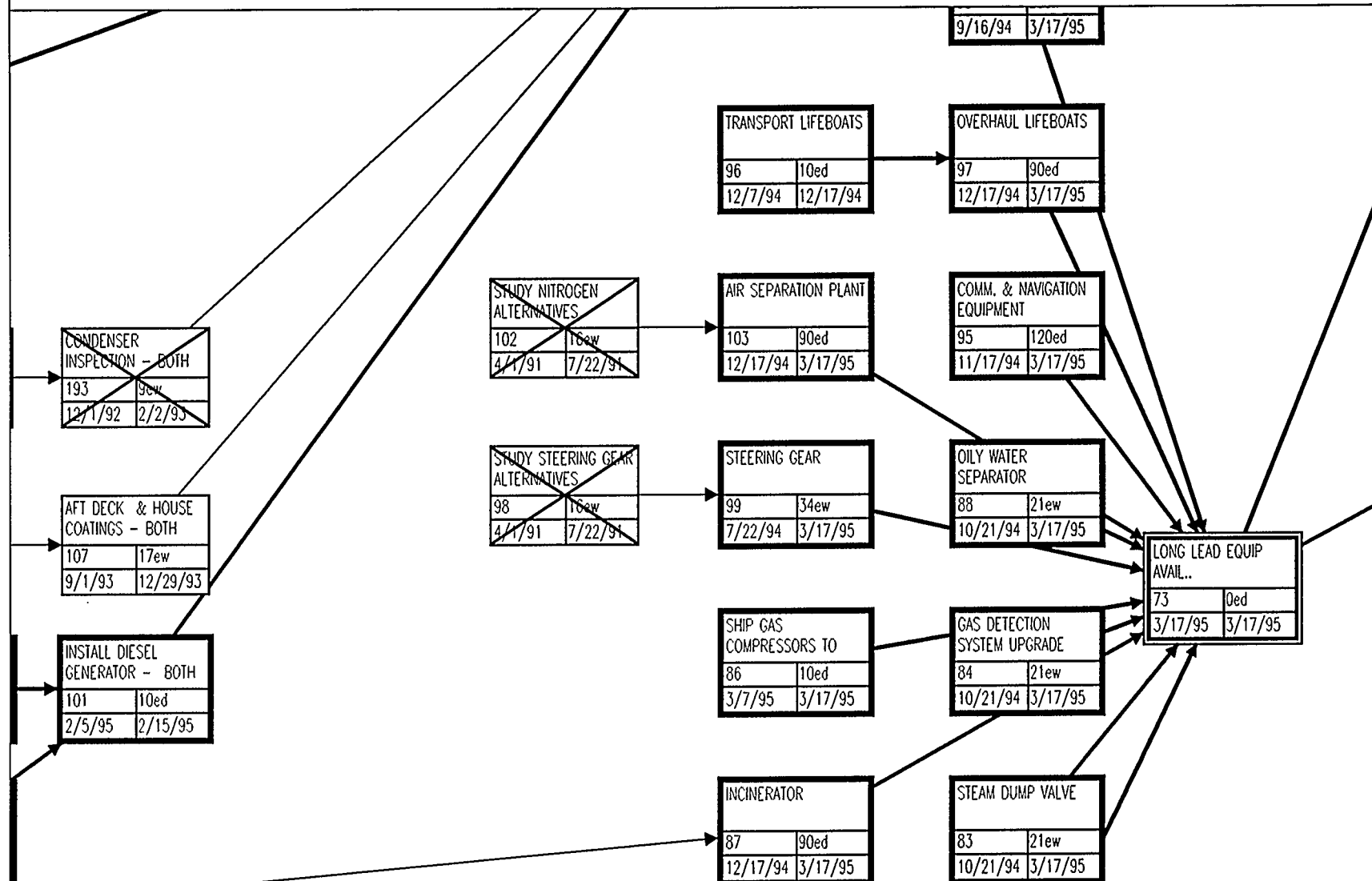


Figure 1

reactivation work plan and schedule.

Boilers and Condensers.

Boilers and condensers were also of unknown condition and, therefore, subjected to long schedule times to plan for the worst case. The boiler refractory was removed and the tubes were cleaned. This allowed detailed examination of the condition of the boiler and permitted shorter schedule times to be used with greater confidence. Similar actions were taken with the main and auxiliary condensers.

Pumps.

Large pumps in the engine room, such as the main circulators, etc. were also subjected to long schedule times due to unknown condition. In particular, the condition of pumps used to ballast/deballast the ship in lay-up were suspect due to long periods in the corrosive seawater atmosphere; this is because the pumps had to remain in service and could not be put under a lay-up condition. Like the turbines, the engine room pumps have all been overhauled prior to full reactivation and the work removed from the reactivation, work plan and schedule.

Cargo Pumps & MI Cables.

Electrical problems with other, similar pumps/and Mineral Insulated (MI) cables on other vessels dictated an assessment of the cargo pumps. Like the turbines, if parts were found to be necessary during reactivation, lead times could be as high as one year. As a result, all of the cargo pumps were removed and rebuilt using new bearings; the submerged electrical ends were thoroughly tested and then reinsulated using the vacuum impregnation process with an epoxy insulation for the field winding(s) which is suitable for cryogenic temperatures.

Deck Electrical Junction Box and Cargo instrumentation.

Similar lead time problems were also found with regards to instrumentation systems in the cargo system. Overhaul of this equipment is currently being carried out prior to shipyard reactivation.

Cargo (Cryogenic) Valves and Valve Actuators.

Several valves were opened up for inspection. Approximately 90% of the valves inspected had damaged soft seats and seals. Lead time on replacement parts was approximately 10 months. Due to the critical nature of this equipment, the decision was made to replace all soft components in all of the valves and perform the overhauls prior to shipyard reactivation. As the valves are being overhauled, further component replacements have been found with similar lead times.

Gas Compressors.

The original equipment manufacturer was no longer in business. A qualified service representative had to be located. Any parts needed had to be fabricated on a custom or "one-off" basis. As with items already discussed, the potential for massive schedule delays was very high due to long lead times on parts. The compressors were removed and shipped to the service company. They have been overhauled and are in storage under the care of the service company until needed during shipyard reactivation.

The following reactivation work items were identified as having significant schedule impacts after reviewing the shipyard prepared schedule and planning documents, with the bidding shipyards. Although these items do not have unknown long lead part requirements, they do impact the overall schedule due to conflicts with other reactivation work.

Blasting and Coating of the Trunk and Main Decks.

The blasting and coating of the trunk deck was an intricate job due to the large amount of deck equipment, piping and related outfit. In addition, the deck was showing severe corrosion in many areas due to standing water during the ten years of lay-up. For these reasons the trunk and main decks forward of the accommodation house were blasted and coated during the summer of 1992. The job turned out to be significantly more time consuming than expected, and would have caused massive schedule delays had it been performed during the shipyard reactivation period. The masking job alone ended up taking two weeks, far in excess of the time scheduled. Due to environmental considerations, clean-up involved tremendous vacuums and hoppers that had to be loaded/unloaded at least daily and repositioned more than once each day. The entire

job, per ship, was estimated at 90-120 days in good weather, and ended up exceeding this time by a considerable amount. This posed a scheduling problem, increasing total reactivation time, since nothing else could be done on deck or in the cargo tanks during the entire blast/coat job. By performing this work prior to the shipyard reactivation period, the planned reactivation time was reduced and the further deterioration of the deck was averted.

Blasting and Coating the Aft House.

While the blasting and coating of the aft house will be a less intricate job than the trunk deck work, it still requires significant masking and covering of the front of the house to limit grit blast damage and clean-up to just around the house area. During the 90-day period in which the blasting and coating work is to take place, each yard assumed little or no engine room work will be carried out as most all access to the house and casing will be sealed. If these seals are violated, then engine room machinery work could become contaminated. Consequently, the blasting and coating of the aft house has been designated as a pre-reactivation project and is currently scheduled for the fall of 1993.

Most yards agreed that if the trunk deck and aft house blasting and coating tasks were carried out before entering the reactivation yard, that topside and bottom painting could take place in drydock with interdiction barriers placed between the sheerstrake and drydock wingwall. In this way, work above the sheer strake could continue while the ship is in drydock.

Auxiliary Diesel Generator Room.

The ships are to be retrofitted with a standby Diesel Generator (D-G). A new room is to be fitted below the main deck in an existing stability tank. The stability tank was not used in service and is in a convenient location. The work involves slotting the deck to rig plate through for steel fabrication, mounting a large diesel generator and switchboard, and then running electrical and ventilation services in the new room and to the Engine Room. Carried out in conjunction with other work in a short term reactivation, this installation blocked the major casing access to the Engine Room and blocked major pathways across the ship for handling materials for other tasks.

Opening up the deck slot, dumping the prefabricated steel below deck and quickly closing the slot would solve most of the deck interference problem. However, this approach would create a bigger problem below deck in attempting to sort and move prefabricated structure in a confined space. If this steel work were to be completed and the D-G set and switchboard installed, all the shipyards agreed that the remaining electrical, ventilation, testing and other work could be carried out in a 4-month reactivation period. As with the aft house blasting and painting, this work has been designated as pre-reactivation and is scheduled for early 1994.

Cryogenic Work.

Cryogenic work covers many cargo related items on deck and in the cargo tanks, where a clean, undisturbed workplace is necessary. Lifts must be carefully made under controlled conditions as any resulting damage could be extremely expensive and could delay schedules significantly. Again, in discussing schedules with the bidding shipyards, it was clear that some shipyards had stopped all other work in the vicinity whenever cryogenic equipment work was undertaken. It also became clear, upon reviewing shipyard bids, that technical expertise with regards to cryogenic equipment varied widely between the bidding shipyards. Cryogenic repair work, such as cargo pump overhauls, etc. was, therefore, designated as pre-reactivation work. The cargo pumps were removed, overhauled and reinstalled in 1991 & 1992. Other cryogenic work continues in accordance with the pre-reactivation work plan.

PRE-REACTIVATION PLAN

Working with the shipyard in which the LNG carriers are laid up (that shipyard is also bidding on the reactivation work), quotes were solicited for doing the above tasks prior to reactivation as separate pre-reactivation work items. As noted, competing shipyard bidders agreed to the items that should be carried out. The order or priority under which pre-reactivation tasks were/are carried out is based upon: preservation of the ships and the capital asset that they represent, budgets and, lastly, a logical sequence of work from a technical viewpoint. Preservation of the ship is based upon preventing further degradation of the ship and equipment. It was for this reason

that the trunk deck blasting and coating was one of the first tasks to be performed. As with all projects, there are also budgetary considerations. The principle budgetary constraint is to delay all outlays as late as possible consistent with preserving the ship and reducing the reactivation period. A logical work sequence is important, but has been overridden in several instances by the need to preserve the ship and delay cash expenditures. For instance, logically it would be preferable to do the steel work for the diesel generator room prior to blasting and coating the main deck in this area. Unfortunately, budget constraints and the need to prevent further degradation of the main deck override logical work sequence, therefore the blasting and coating will be performed prior to the diesel generator room steel work. This means that repair of the coating on the main deck, therefore, will be required, increasing overall cost slightly.

The cost for carrying out these tasks at subcontractor's (and shipyard's) convenience, without the interference of other work was 15 to 30% less than the bid figures for the same task in reactivation. All reactivation tasks were bid by the bidding shipyards as stand alone tasks, where overhead and other costs were included in the items. Therefore, direct comparisons between doing a task during the reactivation period and doing the task as pre-reactivation work could be made.

By carrying out one to three major tasks simultaneously as pre-reactivation work, they can be supervised and inspected unencumbered by the press of a reactivation schedule deadline. Although accomplishing work within the planned schedule is still important, the schedule can, nonetheless, be adjusted when needed with greater flexibility without the press of an in-service date for the ship. Costs can also be readily controlled to the satisfaction of owner and contractor.

The trunk deck coating job is an example of the quality that can be achieved when the schedule allows flexibility. This work was accomplished in the spring and summer of 1992, and ended up being performed during an extremely rainy, wet spring. Consequently it took almost twice as long to complete as predicted. The blasting work and subsequent painting with a inorganic zinc/surface tolerant epoxy coating system cost nearly three-quarters of a million dollars per ship. Properly done, the system should last at least 10 years with reasonable

maintenance. If this work had been accomplished during the reactivation period, the press of an in-service deadline would have required that less than optimum conditions for applying the coating system be accepted in order to meet the schedule. The final job would have been inferior to the job carried out in pre-reactivation. If the work had been accomplished under these conditions, and coating breakdown occurred in two years, the cost to carry out a coating job at sea or to remove the ship from service would be much higher than the cost of the original work. Doing such work at sea with entrained salts and a damp atmosphere would also give limited service life to the coatings.

LAY-UP MANAGEMENT

While Figure 1 shows a portion of the Macro Reactivation Plan, consideration also had to be given to the management of the continued lay-up of the ships. The minimum manning in lay-up (with no lay-up maintenance routine) consists of three watchmen on a 24-hour rotation. The annual cost of labor under such an arrangement is estimated at \$91,250. Unsecured lay-up berths on the East Coast, where guard service would be required, ranged between \$500 and \$2,500 per day depending on the length of lease and available shore services. Full utilities (power, water, steam and sewage) ranged between \$250 and \$350 per day. Assuming a lower median cost of \$1,000 per day for berth and services, the total estimated cost for guards and a berth is \$456,250 per year, without performing any maintenance or preservation work.

When reviewing the critical work items discussed previously, it was clear that a shore crane would be helpful in carrying out these tasks. Man-handling equipment over pipelines and down deck slopes was thought to be inefficient and dangerous. A lay-up berth with a higher level of services, therefore, was sought.

A lay-up berth was located in a secure shipyard where the increased berth and services charge was offset by the savings in not having to hire a guard service. Nearly 12% of the annual lay-up berth cost was saved, with the added advantage of having shipyard support, crane service, a superior berth from a mooring and fendering standpoint, and superior weather protection.

It is common for laid-up vessels to either retain senior sea-going engineering staff or to

employ shoreside engineers who maintain the ship, with daily, weekly and monthly inspections, rotations of machinery, electrical insulation resistance (megger) readings, etc. As U.S. crewed vessels, the estimated cost of retention of the four (4) senior sea-going marine engineering staff for salary, benefits and food stores would run about \$2,500 per day or \$912,500 per year per ship. Employing a shoreside manager (ex-chief engineer) and two shore based lay-up engineers together with 2 to 4 laborers and a secretary totaled a little over \$500,000 per year. Maintenance schedules were developed with the conclusion that this shoreside staff working eight-hour days could manage the lay-up of two ships and, therefore, the cost would be approximately \$250,000 per year per ship.

The maritime crew alternative gave a 24-hour a day presence onboard (the 4 senior engineers were assumed to live on board the ship) and would maintain a 7-day a week coverage of the ships. Under the shore lay-up management scheme, the ships would be unattended for 16 hours each day and on weekends and holidays. While a locked gangway entrance and shipyard gate with guard provided satisfactory security, the prospects of fire on board, flooding of a machinery space, adverse weather conditions and other on board emergencies needed to be addressed to satisfy owners/charterers and underwriters concerns and requirements.

An alarm system utilizing modern electronics, interfaced with ship's existing systems, records fire, flooding and other perils, and notifies the necessary staff and shipyard personnel via telephone for appropriate response. The addition of beepers for shore staff lessened the impact of having the "duty" where designated personnel were "on call" and had to remain at the telephone number programmed into the alarm system. The total cost for all hardware installed was about \$12,000 for two ships. In nearly 3-years of lay-up, using this approach, the system has performed satisfactorily.

LAY-UP ROUTINES AND PRE-REACTIVATION WORK

Lay-up crews involved only in repetitive lay-up tasks, with no specific goals or schedule, tend to grow inefficient and lose initiative. As it was clear that some pre-reactivation work had to be carried out, as discussed previously, the decision was made to hire additional staff, and to inte-

grate lay-up and pre-reactivation tasks. An example of a portion of the 1994 work plan is shown as Figure 2, often referred to as a "GANT" chart, which gives start and stop dates for tasks and is designed to make the best use of labor and weather. Figure 3 shows projected manpower allocation for engineers to carry out the 1994 work plan, a similar chart is also utilized for laborers. Manpower that is over-allocated is either rescheduled or additional personnel are brought in. Because of weather, work usually peaks in the summer and fall. However, as a large amount of outside blasting and painting is to take place in the fall of 1993, other deck work is going to be suspended due to work conflicts.

Weekly meetings are held on board with management and staff to review progress, tool requirements, equipment status, spare parts levels and consumable requirements. Monthly budgets have been established for labor and supplies. Worker productivity has been maintained at a high level with substantial progress made on pre-reactivation work items. The majority of cryogenic system work is being carried out by trained, in-house staff, lessening the need for outside contractors and, thereby, reducing overall cost while still maintaining a high degree of quality.

RECOMMENDATIONS FOR OTHER LAID-UP VESSELS

The lessons learned on the lay-up/reactivation process of the subject LNG carriers may be applicable to other laid up vessels as follows:

Planning.

Project planning can be extremely beneficial to managing ships in lay-up. Because a schedule, with milestones, is created, and progress can be tracked, management and worker efficiency remains high, as the schedule and milestones are met. By reviewing the lay-up in the context of an overall plan, problem areas can be discovered early, before reactivation begins, and corrective actions taken. The inevitable schedule changes can be more readily accommodated, and the "what if" questions with regard to reactivation can be answered with more accuracy. Ultimately, this will reduce the cost of reactivating the ship.

Where more than one operator or shipyard

Pre-Reactivation Work Plan

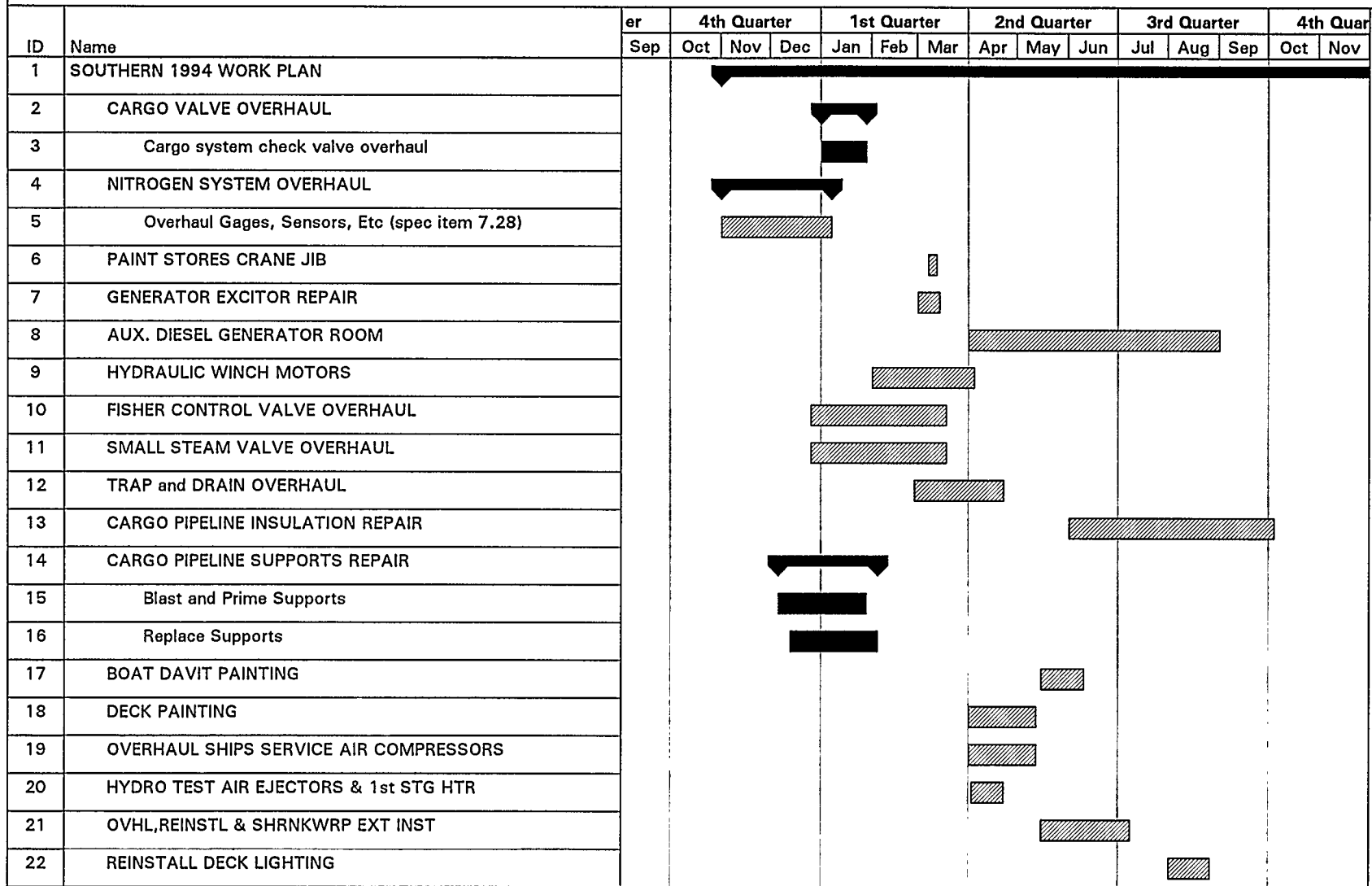


Figure 2

Manpower Allocation Table

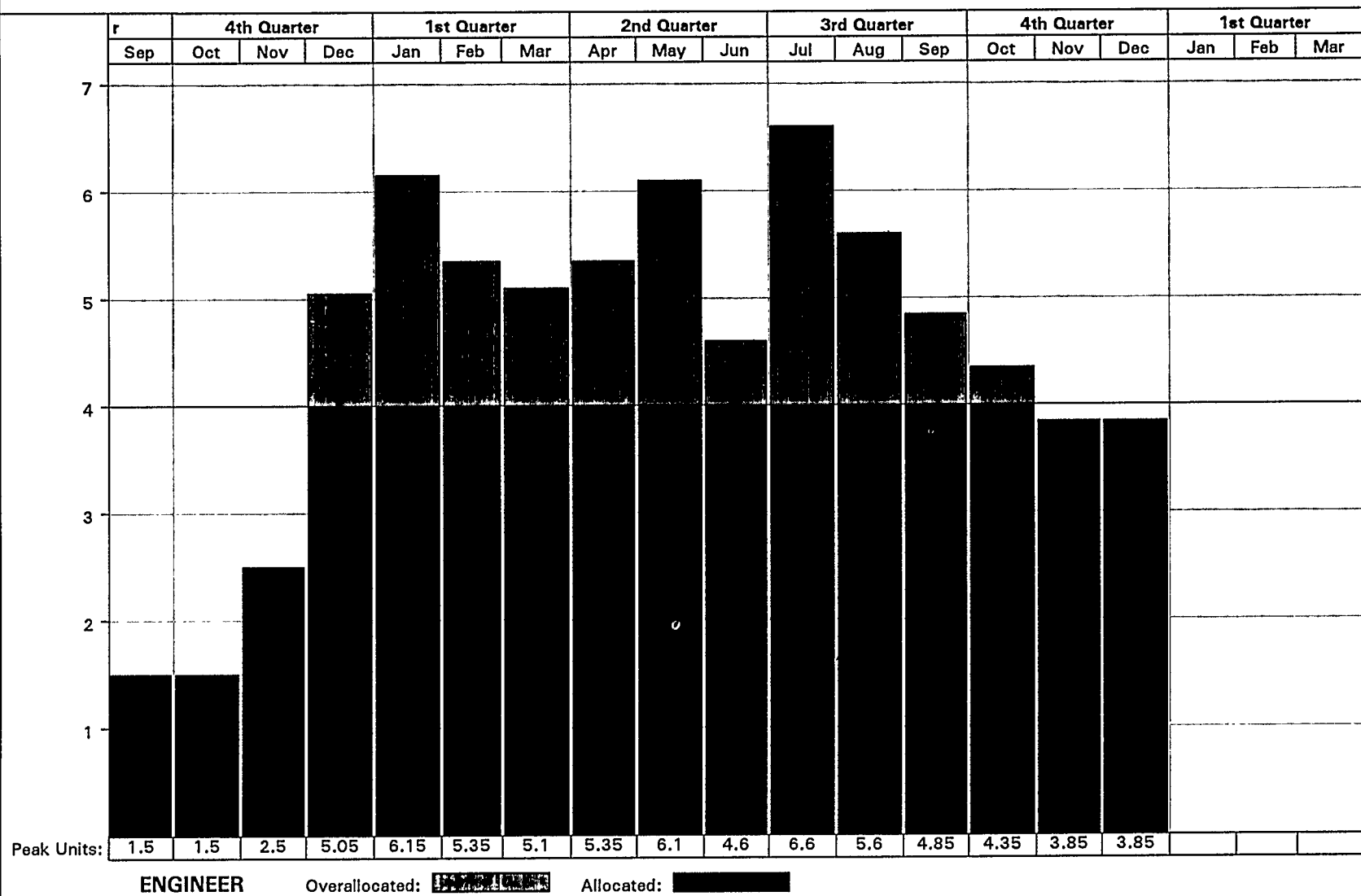


Figure 3

may be involved in the lay-up and reactivation of an RRF vessel, a common, computer-generated work plan provides needed continuity and documentation not available otherwise.

Drydocking.

There is a diminishing availability of drydock space in the U.S to accommodate medium to large size vessels, Reference 1 shows only 10 commercial shipyards on all coasts with substantial drydock facilities. Most East Coast yards require 6-12 months notice for any drydocking, and cannot afford to displace regular repair customers in order to accommodate the two, back to back, 25-day drydockings that would be required for delivering the subject LNG carriers on the desired in-service date. Therefore, long-term plans for reactivation may have to be tied to a specific drydock date, with changes in the reactivation schedule moving forward and back as necessary to meet that date.

For RRF vessels, drydockings should be carried out when required rather than seeking waivers for delay of drydocking until a vessel is reactivated. Ablative type bottom coatings should be applied to laid up vessels. One of the subject LNG carriers has an ablative bottom coating. It has been in the water for 13 years and to this day has no permanent fouling. Her sister-ship, moored alongside for the last 13 years, with a conventional anti-fouling paint, is heavily fouled. With the use of ablative anti-fouling bottom coatings, drydockings for RRF vessels might be scheduled based upon time in service, as opposed to fixed intervals between drydockings.

Major Machinery Overhaul.

A lay-up period is definitely a good time to conduct major machinery overhaul. Recognizing that all RRF ships must be ready in a limited number of days, major machinery overhauled should be conducted on a staggered basis so that only a certain percentage of the RRF fleet is in machinery overhaul condition at any one time and, therefore, has a longer reactivation time. Instead of categorically purchasing all spares needed for overhaul of equipment in service, it is better to open and survey the equipment in lay-up and make specific purchases in a timely, cost effective manner. Often, equipment with worn parts, such as pump internals, is better off being

repaired with new, long life synthetic materials than with "original equipment" replacement parts.

System Testing.

Frequently a ship in lay-up status for a long period has poor system readiness when reactivation is started. When there is a short time available to reactivate, especially with RRF ships, great sums of money are spent on expedited materials, round-the-clock labor and increased management. The question is always asked "Why weren't the problems and deficiencies known before?" Thus, in addition to regular lay-up activities, critical systems need to be tested, run and/or cycled routinely, and repaired as necessary. Fluid systems that are preserved by coatings, treatment or D-H should be visually checked, but any active system with fluid in it, such as steering gear, main engines, etc. should be operationally tested at regular intervals. The results of these tests can then be integrated with the lay-up management plan, and resources allocated so that the ship will be able to be reactivated in the time frame and budget allocated.

CONCLUSION

Experience with the lay-up and reactivation of LNG carriers has shown the importance of applying project management techniques to vessel lay-up. When evaluating the cost of vessel lay-up, overall costs including the cost of reactivation should be included. Reducing up-front lay-up costs can dramatically increase reactivation costs and the ability to meet required delivery schedules, negating all perceived benefits of the reduced lay-up costs. Project management techniques also enable better utilization of available lay-up manpower, further reducing overall costs.

REFERENCES

- 1) Report on Survey of U.S. Shipbuilding and Repair Facilities, U.S. Department of Transportation, Maritime Administration.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

<http://www.nsnet.com/docctr/>

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